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THE ADDITION OF AUTOMATIC TEMPERATURE AND PRESSURE SENSORS TO UNDERWATER GAMMA SPECTROMETER

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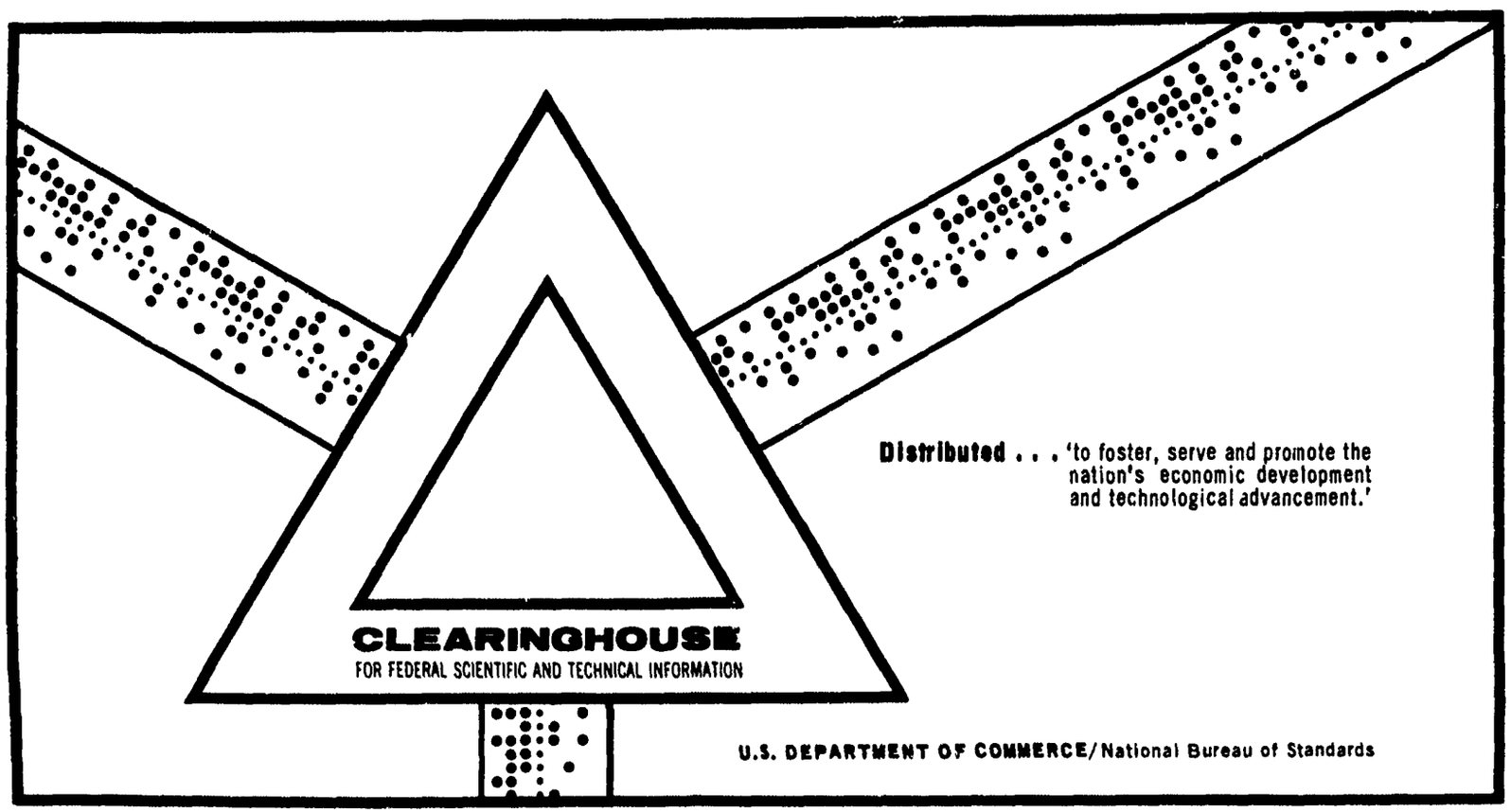
24 March 1969



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ABSTRACT: Radioisotope gages to measure temperature and pressure were incorporated into the Naval Ordnance Laboratory's Deep Underwater Gamma Spectrometer. With this change underwater radiation spectra can be related to other oceanographic measurements. The radioisotopes, 204-Tl and 57-Co, are mounted on conventional sensors, so that the radiation intensity reaching the detector is a function of temperature or pressure. Energy analysis separates the gage counts from each other and the environmental radiation. Only 5% of the energy scale is used for these gages. If environmental spectra were not required, this technique could be expanded to accommodate 20 gages on 1 detector.

U.S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

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The Addition of Automatic Temperature and Pressure Sensors to Underwater Gamma Spectrometer

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E. F. SCHREITER
Captain, USN
Commander

Z. I. SLAWSKY
By direction

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SUMMARY

A scintillation spectrometer is used to measure the gamma (γ) spectrum for determination of radioisotope concentrations in the water. Devices for measuring temperature and pressure have been added to it. These use low energy γ sources (204-Tl and 57-Co) which move past radiation absorbers so that the intensity of their γ-ray peaks is a function of the temperature and pressure. Subsequent analysis of the spectrum documents these conditions as well as the concentration of radioisotopes in the water.

Pressure gages tested had ranges and accuracy corresponding to depths of 0 to 270 ft ± 2 ft, and 0 to 6,000 ft ± 30 ft. The temperature gage's range is -18 to +32°C ± 0.4°C, and its time constant is 0.2 minute^{-1}. These gages use only the lower 5% of the 0 to 3 MeV energy range, so they do not interfere with environmental spectra. Alternatively, 20 gages could be monitored simultaneously by 1 detector.

BACKGROUND

Since 1960 a γ spectrometer has been used to measure concentrations of radioisotopes in water. The underwater probe contains a 5" diameter by 5" high NaI(Tl) scintillation crystal and a phototube (Fig. 1). Improvements on the initial design produced a simple, reliable instrument with high efficiency, sharp energy resolution, and low background. Similar probes have been supplied to the Naval Oceanographic Office and the University of Washington. Recent measurements in rivers and lakes have shown that these probes can monitor the radioactive discharge from nuclear power stations well below the maximum permissible concentrations. The same probe monitors the silt content of the water by the naturally radioactive isotopes contained in the suspended solids. Computer programs have been developed for computation of radioisotope concentrations from the γ spectra.

OBJECTIVES

The first goal was to make the underwater radiation detection system more complete by measuring Bathythermetric (BT) data with the spectrometer instead of relying on either separate measurements or adding measuring devices to the probe which were less reliable and more difficult to use than the probe itself. A second goal was to show that more than one radiation gage could be used with a single radiation detector. This may be the beginning of a new system for multiparameter gaging. These goals are possible because the spectrometer identifies the energy of the γ radiation striking it. Therefore, by using sources of different energy, the spectrometer will identify the source of the radiation.

NUMERICAL METHODS

In the scintillation spectrometer γ rays entering at one energy will give an intensity maximum at their characteristic energy plus a continuous distribution of intensities at all lower energies. Therefore the counts recorded at some energy E_2 must in general be corrected for γ rays from a higher energy (E_1) source depositing less than their characteristic energy in the crystal, and γ rays from a higher energy source which have lost part of their energy before detection. These corrections are usually combined into a single correction factor which is a function of: the intensity of the higher energy source (I_1), the energy of the higher energy source, and the energy of the lower energy source: $F_1(I_1, E_1, E_2)$. So, the total intensity at some energy (T_n) is a function of the source strength at that energy (I_n) plus all of the interfering higher energy sources. The desired intensity may be found by solving the equation:

$$I_n = T_n - \sum_{i=1}^{n-1} F_i(I_i, E_i, E_n) \quad .$$

This is easily solved, if F_i is known for each source. The maximum energy source is measured without interference, and it is used to correct the intensity of the source at the next lower energy. Both of these are used to correct the intensity of the third highest source, and so on. Mathematics may be avoided by electronics. This may be done by digital circuitry either on line or off line. However, it may also be done on line by analog circuitry. Ordinary pulse height analyzers are set so the output of each one is at the characteristic energy of one source. Each of these is connected to a ratemeter. The output of each ratemeter is split into two parts. One part is used to correct all ratemeters at lower energy. The other part is corrected by signals from all ratemeters reading higher energy, displayed, and recorded. The correction voltage from the ratemeter generates an output equal to $-F(I_i, E_i, E_n)$. This signal (and all the other signals from $i = 1$ to $n - 1$) is connected to the correction input of the n^{th}

ratemeter. The correction modifies the n^{th} ratemeter's output so that it responds only to the n^{th} source. Thus each ratemeter reads one gage only.

RESULTS AND DISCUSSION

Figure 2 shows the γ spectrometer. Figure 3 shows the pressure gage and three views of the temperature gage. This system was tested at sea in August 1967. The results are summarized below:

Depth ft	Pressure psi	Pressure Gage Counts/Minute	Temperature Gage Counts/Minute	Temperature Counts Corrected for Pressure Counts
30	13	1,320	1,570	1,380
100	45	1,390	1,630	1,420
300	134	1,440	1,500	1,300
1000	445	1,100	1,030	872
2000	890	706	771	677

The 57-Co (122 keV) source on the pressure gage is set at the edge of the hole in the shield (see Fig. 3). Then, as the pressure bends the Bourdon tube the source moves so that it is over the lead instead of the hole. The source was incorrectly positioned for the above test, so that it moved across the hole before going past the edge. Therefore the counts increased to a maximum near 300 ft and then decreased with depth. The 1,000 and 2,000 ft readings are used to evaluate the accuracy: For a 10-minute count the change is 3,940 ± 3.4%. So the gage can be read to ± 3% of 1,000 ft or ± 30 ft. Since the depth rating of this Bourdon tube is 6,000 ft, it can be read to ± ½% of full scale. The 30 ft error is not important at depths greater than 300 ft. In laboratory tests the change of count with position was much larger, allowing a ± 4 ft error on a 6,000 ft gage. However, for accuracy at shallow depth we have a gage rated for 270 ft which measures to ± 2 ft.

The temperature gage uses 204-Tl (77 keV γ) mounted on the pointer of a conventional thermometer. A tapered shield translates the thermometer reading into radiation intensity. In Figure 3 we see, from left to right, the thermometer, the thermometer with its shield, and the brass thermal contact on the bottom of the thermometer. This thermometer is inside a steel probe, so it will not indicate the true water temperature until the probe's interior reaches the outside temperature. Styrofoam insulation around the inside end of the probe allows the probe wall to approach the water temperature without changing the temperature of the components within the probe. The only heat sink for this area is the brass thermal shoe on the thermometer. The shoe heats or cools the bimetal element, which is insulated from its steel shield by an air space and a layer of plastic. The temperature gage performed well in the August 1967 test at sea. The temperature was nearly constant in the upper 300 ft, with a slight rise at 100 ft and dropping at 300 ft. Below 300 ft the temperature dropped rapidly. For a 10-minute count of the temperature sensor we have a change of 7,000 ± 152 or ± 2.2% for a temperature change of 20°C. Therefore the error is ± 0.4°C. There are three ways to reduce the error:

(1) Count longer - A three hour count will have an error of ± 0.1°C.

(2) Use a larger source - This source is about 0.01 μc. A 0.2 μc source will reduce the error to less than ± 0.1°C.

(3) Use a steeper taper on the shield - This shield covers the range from -18 to 32°C (0 to 90°F). If the taper on the shield is four times as steep the entire change in count rate will occur over a range of 4 to 20°C and the error will be ± 0.1°C. This lower range is adequate for most ocean waters.

The accuracy is good enough for our present use, and the range covers most environments.

Response time is another source of thermometer error Good thermal contact with the vessel wall gives this gage faster response than our earlier models. The thermal time constant is computed below:

t = time

ΔT = the difference between the water temperature and the thermometer temperature

ΔT_o = the initial temperature difference

Q = the amount of heat transferred from the water to the thermometer

K = the coefficient of heat transfer from the water to the thermometer

Cp = the heat capacity of the thermometer, steel wall, and other nearby parts.

Solving the heat balance we get:

$$\frac{dQ}{dt} = K\Delta T$$

$$\frac{d\Delta T}{dt} = \frac{dQ}{dt} / Cp$$

$$\therefore \frac{d\Delta T}{dt} = \frac{K}{Cp} \Delta T \quad .$$

Integrating we find

$$\Delta T = \Delta T_o \, e^{-\frac{K}{Cp} t} \quad .$$

The time constant $\frac{K}{Cp}$ may be evaluated analytically and experimentally. The controlling K for heat transfer is from the water to the steel, its value is about 60 cal/hr cm^2 °C. (The coefficient of heat conduction through a ¼" thick steel plate is 4,300 cal/hr cm^2 °C.) Likewise, the steel furnishes the major heat sink. The heat capacity for a ¼" thick steel plate is about 1 cal/cm^2 °C. So: $\frac{K}{Cp} = \frac{60}{hr}$ = one $minute^{-1}$ and $\Delta T = \Delta T_o \, e^{-t}$ where t is in minutes. However, a time constant of 0.2 $minute^{-1}$ fits most of the experimental data. The table below shows how this effects the results.

Time Minutes	ΔT °C for ΔT_o = 5°C K/Cp 1	K/Cp 0.2
5	0.03	1.8
10	2×10^{-4}	0.68
15	1.3×10^{-6}	0.25
20	1×10^{-8}	0.09

The statistical error for a 10-minute count is ± 0.4°C, so (using K/Cp = 0.2) one must wait 10 minutes, then count 10 minutes so that the average ΔT during counting is less than ± 0.4°C. Therefore, 20 minutes are required for one temperature reading. This is no problem, as the typical counting time is three hours. When a fast response is required the thermometer must be placed in the water.

Another important error in both pressure and temperature results is the error in gain. Separate energy intervals must be determined for each gage, and an error in gain causes an error in this interval. The interval on the multichannel analyzer is known to ± 0.1 channel. In this test three channels were used as the energy interval, so the error was ± 3% which corresponds to ± 30 ft on the pressure gage and ± 0.6°C on the temperature gage. This error is easily reduced. The energy scale is expanded, so that 10 channels are used to cover the interval. Then the error is only ± 1%. The gain cannot be changed for the γ spectra measurement, since these spectra cover a wide energy range. Precise determination of pressure and temperature may be made in a 10-minute counting interval after the ocean spectral measurement. It is unfortunate that no increased accuracy from the gages is obtained by the long γ spectrum count. Use of a log energy scale would allow more precise determination of the entire range, thus measuring the gages and environmental radioactivity in one spectrum.

These gages may be compared with commercial gages: Our pressure gage error (± ½%) is the same as the error in the HYTECH Model 4006 pressure transducer. Our temperature gage's error (0.4°C) and response time (1 to 5 minutes) are comparable with the BRAINCON Type 146 (0.3°C, 5 minutes) or the Geodyne Model A-119-4 (0.2°C, 2½ minutes).

CALIBRATION

To interpret the results, some fraction of the counts from the pressure gage must be subtracted from the counts in the temperature gage's energy range. A test stand (Fig. 4) has been built to determine this fraction. It holds a 5" diameter by 5" high NaI(Tl) crystal, and the 204-Tl and 57-Co radioisotopes in the same positions they have in the underwater probe. The probe wall is simulated by a ¼" steel plate. Shields of varying thickness are placed between sources and detector. Spectra measured in the stand were used to determine the effect of the pressure gage in the temperature gage's energy range. Typical environmental sources add less than 1% to the counts in the gage's energy ranges.

The shields shown in Figure 4 did not duplicate the gages, so components of the gages were used, mechanically held in positions corresponding to various temperatures and pressures. The possible error in this position (20%) makes this calibration less accurate than one determined in the environment. The 1024 channel analyzer used had 2% accuracy in the window width, so that the relative effect of 57-Co on the temperature reading was precisely determined. The results are summarized below:

Condition (Approximate)	Source	Counts/1 Minute in 36 keV Window @ 77 keV	@ 122 keV
80°F	0.1 μc 204-Tl	185	--
60°F	0.1 μc 204-Tl	134	--
40°F	0.1 μc 204-Tl	103	--
20°F	0.1 μc 204-Tl	63	--
0°F	0.1 μc 204-Tl	37	--
30psi	0.1 μc 57-Co	110	300
3,000psi	0.1 μc 57-Co	130	240
6,000psi	0.1 μc 57-Co	130	90

PREVIOUS WORK

Before the sensors described above were made, considerable testing was done with prototype sensors in the NOL environmental test laboratory. These sensors used a 133-Ba (360 keV) γ source, so they could be mounted outside the steel probe. The temperature sensor was a bitametallic coil in an oil filled housing. The pressure sensor used a complete gage, so its dial could be used to check the calibration. These sensors were used tc test a variety of absorber designs for optimum range and sensitivity. Figure 5 shows the prototype temperature sensor. This plastic cased model had slow response, because the sensing element had nó direct thermal coupling to the water. Figure 6 shows one of the tapered shields used with this thermometer. The center hole is for mounting. The prototype pressure sensor is shown in Figure 7. In Figure 8 it is mounted on a small probe for testing. The radioactive source is mounted at the edge of the center hole in the lead shield. Point sources were ordered for this gage, but gave poor sensitivity. Autoradiography of the sources revealed that they were deposited in a ring about ¼" in diameter. Pressing the sources into a 1/8" diameter metal cup improved the sensitivity. Tapered shields for the pressure gage were tested and rejected as they reduced the sensitivity without increasing the range. The final pressure gage is like the prototype, except the gear and dial have been removed. Purchase of specially made components for the sensors turned out to be more costly, and less satisfactory than purchasing standard items and stripping them of excess parts.

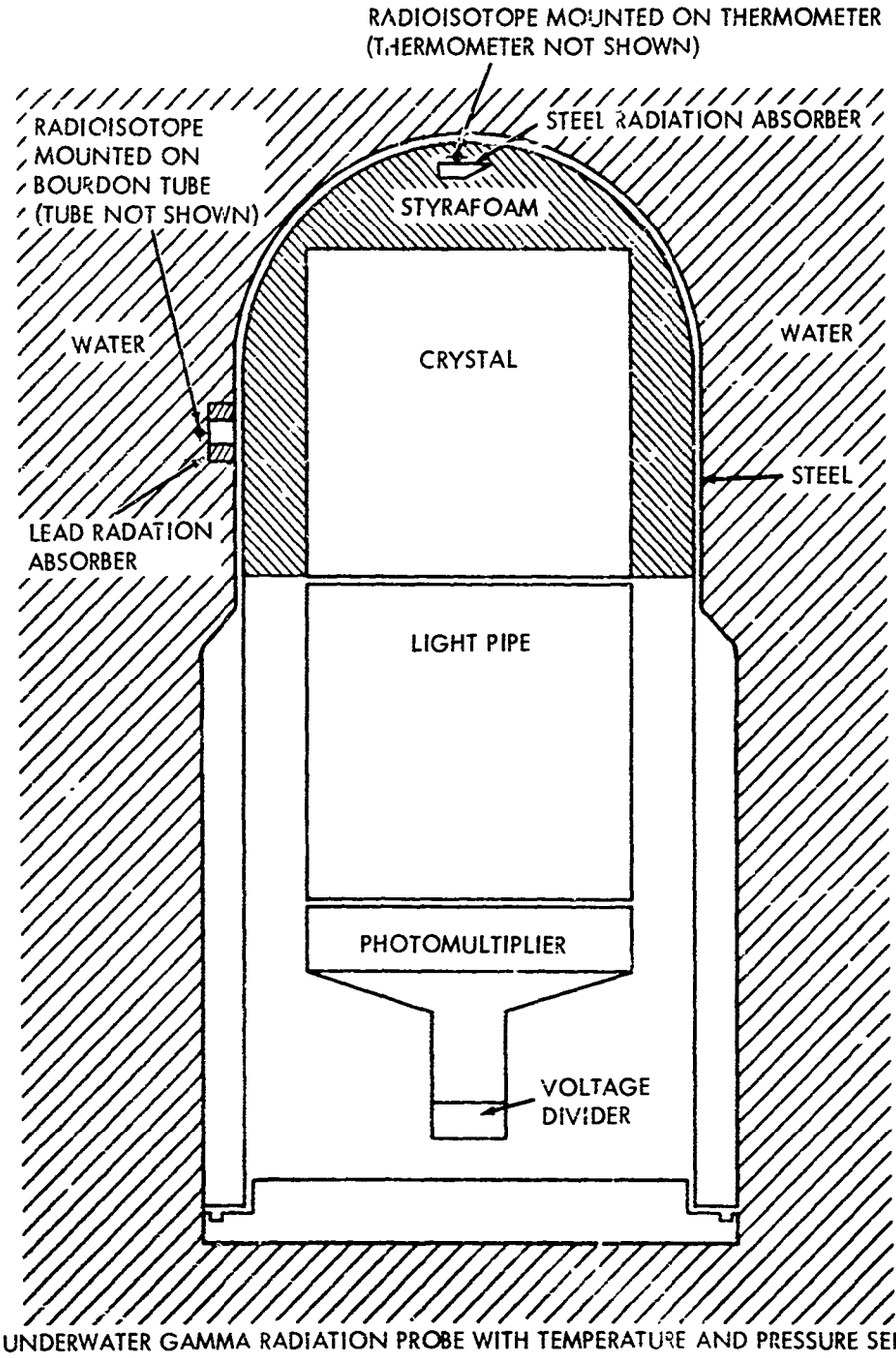


FIG. 1 UNDERWATER GAMMA RADIATION PROBE WITH TEMPERATURE AND PRESSURE SENSORS

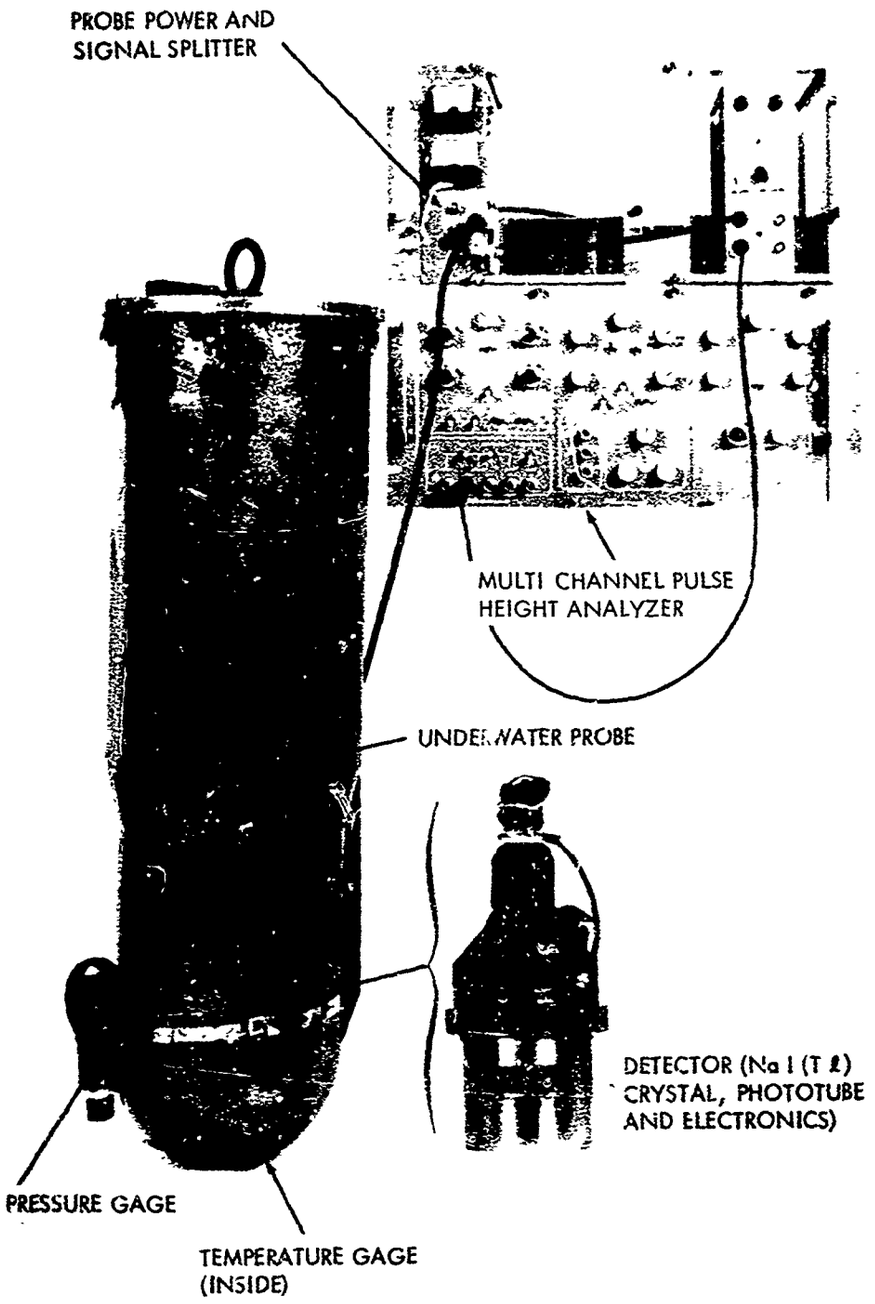


FIG. 2 UNDERWATER γ SPECTROMETER

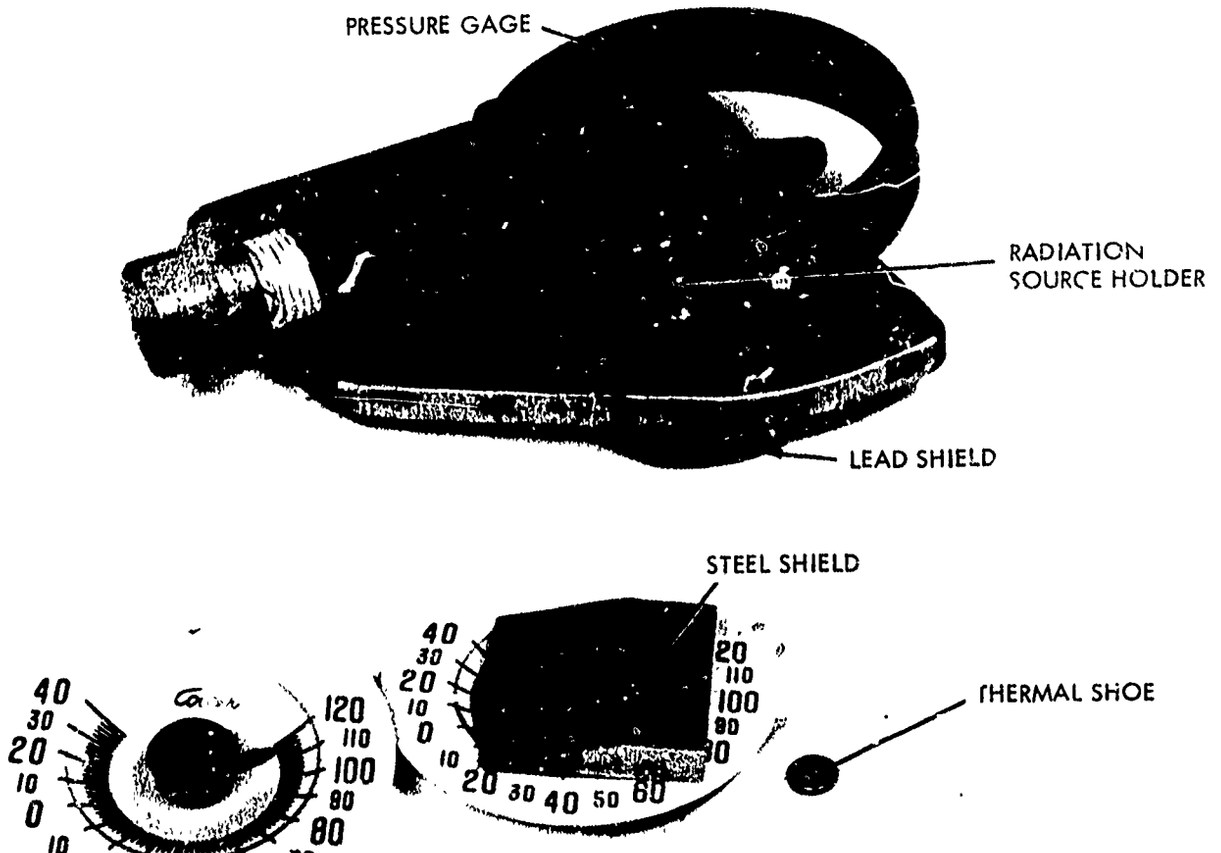


FIG. 3 RADIO ISOTOPE GAGES

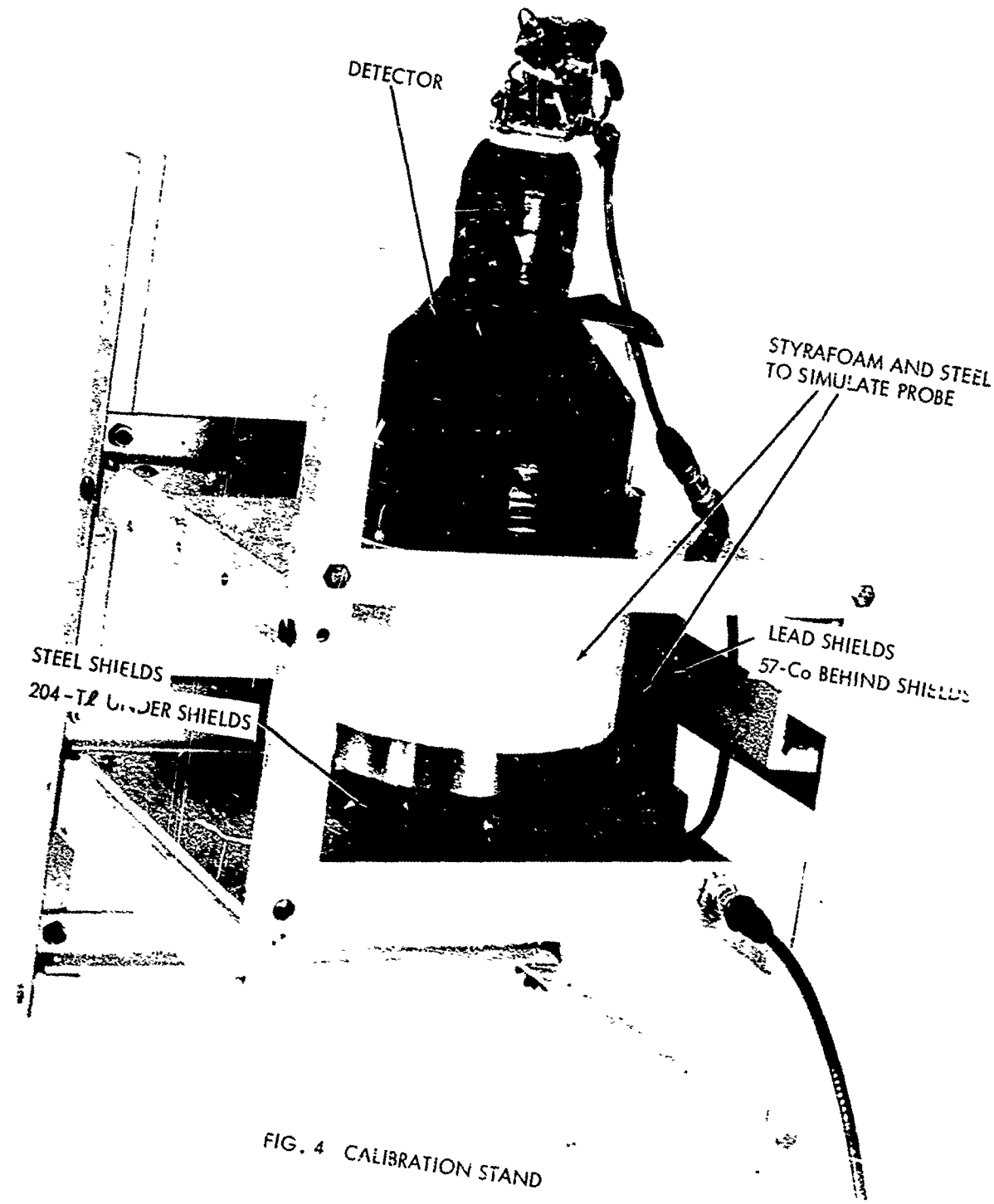
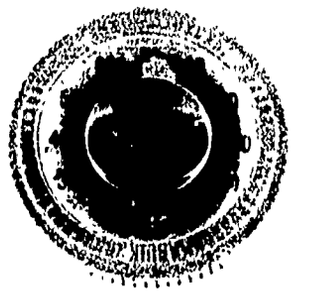
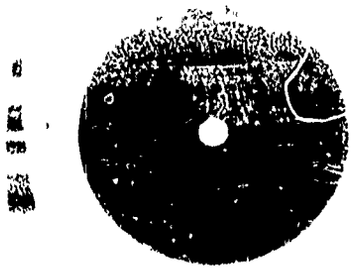


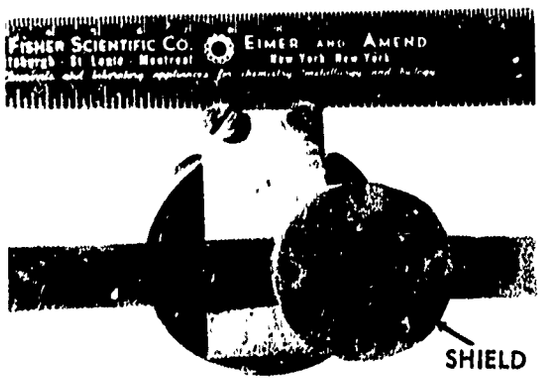
FIG. 4 CALIBRATION STAND



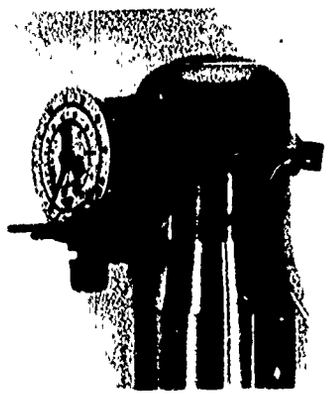
5. ORIGINAL TEMPERATURE GAGE



6. THERMOMETER'S SHIELD



7. ORIGINAL PRESSURE GAGE



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13 ABSTRACT

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Radiation Gaging						
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Bathythermetric						
Radioisotope						
Underwater radiation spectra						

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